Topic E – Enviro Chemistry Part 6 – Water Treatment

IB Chemistry

Topic E – Enviro

Hodder Ed - Talbot

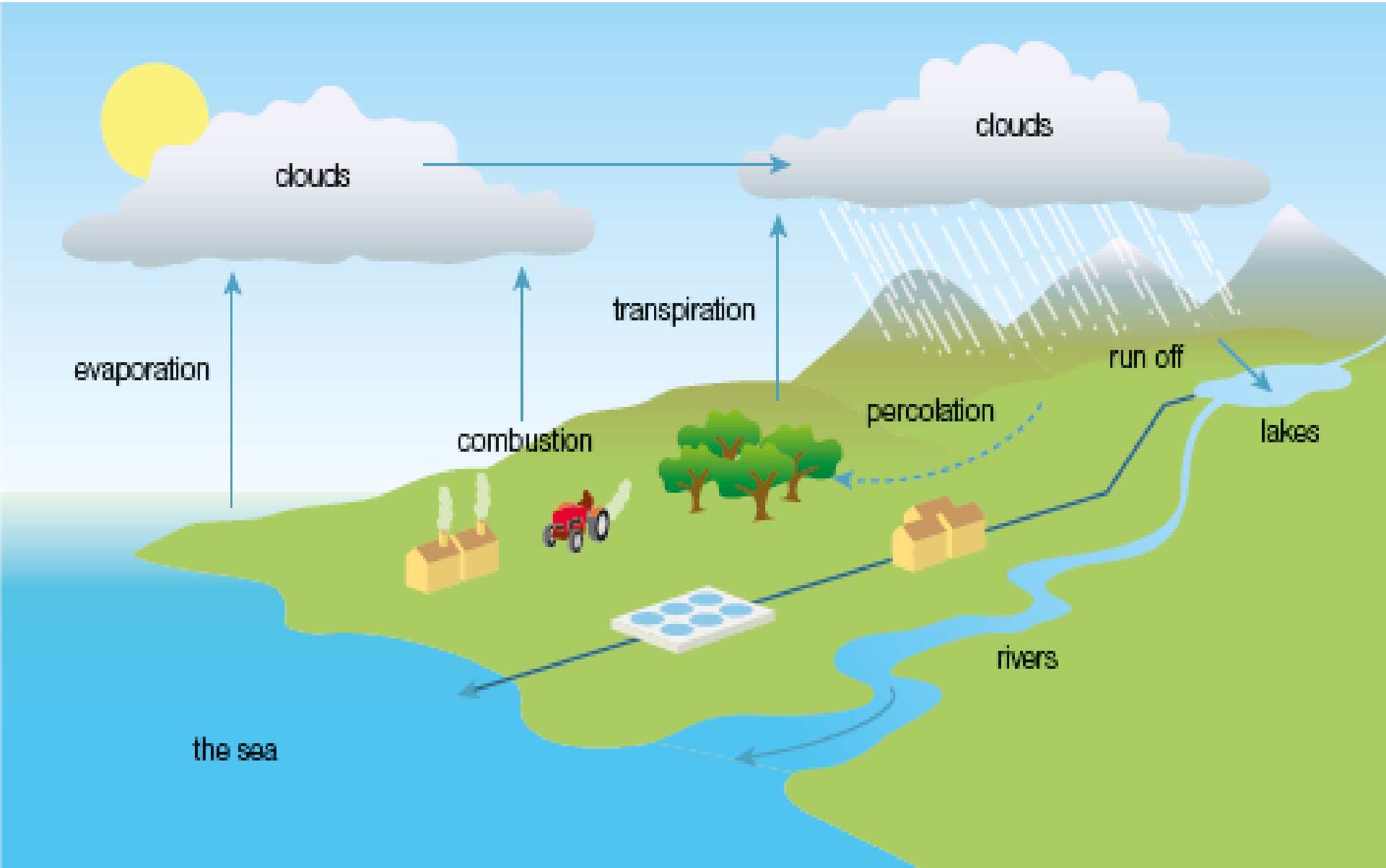
E6 Water treatment -2.5 hours

- E.6.1 List the primary pollutants found in waste water and identify their sources. (2)
- E.6.2 Outline the primary, secondary and tertiary stages of waste water treatment, and state the substance that is removed during each stage. (2)
- E.6.3 Evaluate the process to obtain fresh water from sea water using multistage distillation and reverse osmosis. (3)

E6.1 – Primary Waste Water Pollutants

- E.6.1 List the primary pollutants found in waste water and identify their sources. (2) *Examples include heavy metals, pesticides, dioxins, polychlorinated biphenyls (PCBs), organic matter, nitrates and phosphates.* ***Aim 7:*** *Data banks and spreadsheets can be used.*
- The driving force behind the water cycle is the heat of the Sun.
- Thermal energy from the Sun causes evaporation from oceans, seas, and lakes

E6.1 – Water Cycle



E6.1 – Water and its Pollutants

- Water is an excellent solvent and dissolves many different chemical substances
- As water falls through the atmosphere it dissolves gases, such as CO_2, and pollutants such as SO_2 and NO_x.
- Chemical fertilizers washed off the farmland will add NO_3^- and PO_4^{3-} ions
- River water may contain pesticides, bacteria and oil
- All of these impurities must be removed before it c an be used for drinking

E6.1 – Types of Water Pollutants

- Water pollution falls into two broad categories:
  - **Point sources** – occurs when the source of pollution is clearly identifiable at one point
    - For example: a chemical factory releasing toxic substances into a river
  - **Non-point sources** – describes situations in which water collects pollutants over a larger area, and thus cannot be attributed to a single source
    - Examples: Acid rain polluting a lake, fertilizer run-off which accumulates N and P in compounds in rivers

E6.1 – Primary Water Pollutants

- The primary pollutants found in waste water are:
  - Heavy metals (toxic metals with high A_r)
  - Pesticides (insecticides and herbicides)
  - Chemical wastes (dioxins, PCB's)
  - Organic Wastes (sewage)
  - Fertilizers

E6.1 – Effects of Heavy Metal Water Pollutants

Pollutant	Major source(s)	Effects
Mercury	Man-made sources include: Mercury is used in the industrial electrolysis of brine (Chapter 23). Some paints require mercury compounds for their manufacture. Mercury compounds are used as catalysts in manufacture of some organic compounds. Mercury is released as a by-product of cement manufacture.	Mercury poisoning affects the nervous system, leading to blindness, loss of coordination and paralysis. In 1953 the population of Minamata, a fishing village in Japan, began displaying symptoms of mercury poisoning. A chemical factory in the bay had been discharging mercury wastes into the water. The plankton absorbed the mercury and were eaten by fish, which in turn were eaten by larger fish. In this way the mercury accumulated through the food chain until it reached a harmful concentration. When people ate the large fish they received a massive dose of mercury.
Lead	Lead is no longer used as a petrol additive (Chapter 10), so levels of lead in the environment have fallen. However, lead is still present in the water pipes of many older buildings.	Lead poisoning also affects the nervous system, causing drowsiness, visual problems and psychological effects.
Cadmium	Zinc mining and zinc plating (galvanizing) releases cadmium into the environment. Cadmium compounds are also used as an orange pigment in paints. If rechargeable nickel-cadmium (Ni-Cad) batteries (Chapter 23) are allowed to enter landfills the cadmium can find its way into groundwater.	Cadmium is carcinogenic and extremely toxic. Inhalation of fumes containing cadmium can lead to pulmonary oedema (excess fluid in the lungs) and death.
Chromium	Chromium is used in electroplating (Chapter 19) and in tanneries (leather treatment).	Chromium(vi) compounds are carcinogenic and irritate the eyes and mucous membranes and can lead to blindness.

Table 25.3 Major sources and harmful effects of heavy metal pollutants

E6 E6.1 – Effects of Pesticides, chemical wastes, organic matter, and fertilizers

Pollutant	Major source(s)	Effects
Organochlorine insecticide – DDT (dichlorodiphenyl trichloroethane *or* 1,1,1-trichloro-2,2-bis (4-chlorophenyl)ethane)	DDT is an insect neurotoxin. In the 1950s it was hoped that DDT would allow the total eradication of malaria, and spraying took place in large areas of Africa and Asia. However, it soon became clear that several species of insects had evolved a resistance to DDT.	Declining bird populations (especially of those at the top of the food chain, such as falcons and eagles) were attributed to accumulation of DDT. DDT is soluble in fat, which allows it to build up in animal tissues. The publication of Rachel Carson's landmark book *Silent Spring* in 1962 alerted the world to the dangers of pesticides such as DDT. Today, DDT is banned for agricultural use in most countries, but is still permitted for use in the control of malaria.
Organophosphate insecticides – Parathion, Malathion	Organophosphate insecticides are also neurotoxins. Organophosphates are less persistent: in the presence of sunlight, air and soil they are decomposed. Organophosphates are introduced to the environment by spraying. They are used in agricultural applications.	Most organophosphates will kill unintended species. In particular, organophosphates are highly toxic to bees, which are needed to pollinate crops. In 1995 the Japanese religious cult Aum Shinrikyo perpetrated a terrorist attack on the Tokyo subway using liquid Sarin, a powerful nerve gas.
Herbicides – dipyridilium compounds, phenoxyethanoic acids	Herbicides are applied to crop fields by spraying. The purpose is to remove weeds before replanting crops. After use they are washed down through the soil and eventually enter streams and rivers.	Paraquat, the most common bipyridilium herbicide, is dangerous to humans by ingestion and inhalation. Phenoxyethanoic acids are used as weedkillers. Their most infamous use was during the US–Vietnam war in the 1960s. 'Agent Orange' a mixture of two such compounds, was widely sprayed over the Vietnamese jungle as a defoliant.

Table 25.4 Major sources and harmful effects of pesticides, chemical wastes, organic matter and fertilizers.

E6.1 – Effects of Pesticides, chemical wastes, organic matter, and fertilizers

Pollutant	Major source(s)	Effects
Dioxins	Dioxin, refers to the dass of compounds correctly called polychlorinated dibenzodioxins. Dioxins are produced during the incineration of plastic waste. Dioxins are also formed as by-products during the manufacture of herbicides. Dioxin was present as an impurity in 'Agent Orange'. Dioxins are also present in cigarette smoke and the soot from barbecues.	They are persistent, and, like DDT, they are fat-soluble, which leads to their being concentrated through the food chain. Dioxins damage the heart, liver and kidneys. They are teratogenic, meaning that they can cause deformities in unborn children, and they are suspected carcinogens. Exposure to high dioxin levels leads to the skin disease 'chloracne'. In 2004 the Ukrainian politician Viktor Yushchenko (Figure 25.15) visibly suffered from this condition. **Figure 25.15** Ukrainian former Prime Minister and presidential candidate Viktor Yushchenko, with his face disfigured by dioxin 
Polychlorinated biphenyls (PCBs)	PCBs are a class of organic compounds in which a number of chlorine atoms are attached to a pair of benzene rings. PCBs were used as coolants in electronic components, as sealants, as hydraulic fluids, as additives in plastics and as flame retardants.	Like DDT and the dioxins, PCBs are persistent and fat-soluble, making bio-accumulation possible. The primary victims of PCB poisoning have been sea birds. In humans, PCB poisoning causes liver damage and the skin condition chloracne. The Great Lakes in the USA suffered massive amounts of PCB pollution in the 1950s and 1960s. Consumption of fish from these areas is still restricted today.
Organic matter	Organic matter in waste water usually refers to sewage.	Organic matter may contain plant nutrients leading to eutrophication. Organic waste allows the spread of disease. People suffering from diseases spread by impure water, will produce faeces containing bacteria.
Chemical fertilizers – nitrates and phosphates	Nitrate pollution arises from excess fertilizer that has entered rivers that pass through farmland. Nitrates are rapidly washed out of the soil by rain water. Phosphate fertilizers are less soluble than nitrates, and so are less rapidly leached from the soil. The most important source of phosphate pollution is detergents.	Nitrate and phosphate pollution leads to eutrophication (see Section 25.5). In 'blue-baby syndrome' nitrate ions in water are metabolized to nitrites in the baby's digestive system. The nitrites then oxidize iron(II) in the baby's hemoglobin to iron(III). Iron(III) cannot perform the role of oxygen transport, so the baby suffers a lack of oxygen.

The term pesticide encompasses herbicides (weed killers), fungicides (fungus killers), algicides (algae killers) and insecticides. They are usually artificially synthesized organic compounds. Many of them are bio-accumulative, meaning that they are not excreted by organisms, leading to increasing concentrations through the food chain.

Table 25.4 Major sources and harmful effects of pesticides, chemical wastes, organic matter and fertilizers.

E6.2 – Stages of Water Treatment

- E.6.2 Outline the primary, secondary and tertiary stages of waste water treatment, and state the substance that is removed during each stage. (2)
  For primary treatment, filtration and sedimentation should be covered. For secondary treatment, mention the use of oxygen and bacteria (for example, the activated sludge process). Include the removal of heavy metals, phosphates and nitrates by chemical or biological processes

E6.2 – Waste Water Treatment

- The treatment of waste water before it can be safely re-introduced to rivers takes place in three stages:
  - **Primary treatment** – screening to remove solids, followed by sedimentation of sand, grit and sludge
  - **Secondary treatment** – use of oxygen and bacteria to remove organic matter
  - **Tertiary treatment** – chemical precipitation of remaining organic compounds, heavy metals, nitrates and phosphates

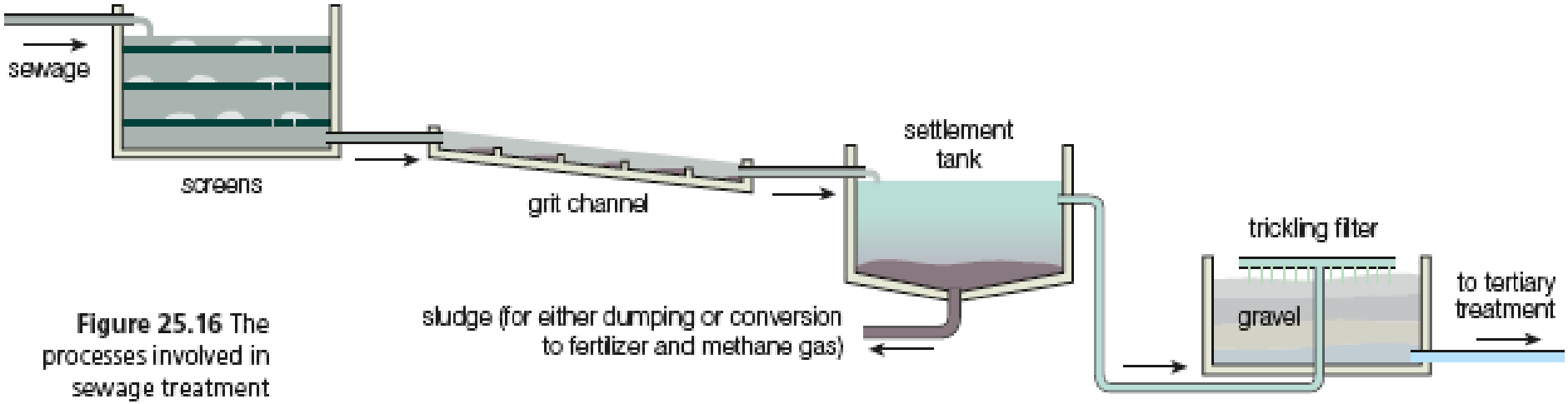


Figure 25.16 The processes involved in sewage treatment

E6.2 – Primary Treatment

- Water is sent through **coarse mesh screens**:
  - Raw waste water contains floating and suspended solid material. This may include paper, rags, wood and plastic rubbish that may cause blockage elsewhere in the treatment plant.
- Water is passed through **grit channel**
  - The speed of the water is slowed so sand and grit settle out. A spinning centrifuge could also be used.
- Water is then passed into **large holding tanks** to settle
  - Fine solid particles form sludge at bottom, insoluble grease floats to top and is skimmed off
    - *Sometimes this treatment alone is enough*

B6.2 – Secondary Treatment

- Secondary treatment **focuses on lowering BOD** by removing organic matter
- The principal secondary treatment involves allowing aerobic bacteria to oxidize the organic matter
  - One method involves pouring of the waste over a **bed of small stones** covered in microorganisms
  - More effective method called the **activated sludge process**. Bacteria and sewage are mixed and blasted with air allowing for the bacteria to multiply rapidly and feed on the organic material. This process removes 90% of the BOD from waste water

B6.2 – Tertiary Treatment

- Tertiary treatment is sometimes called **advanced water treatment** and removes the remaining inorganic pollutants from the water (PO_4^{3-}, N complexes, heavy metal ions).
- This process is very important where industrial point sources such as metal works or chemical plants have led to high [pollutants]
- Nitrogen compounds are removed so they do not contribute to eutrophication of rivers and lakes. There are two common types (ammonium ions, and nitrate ions.)

E6.2 – Tertiary, NH_4^+ removal

- In the tertiary treatment, water is first treated with **nitrifying bacteria**, which **oxidize the NH_4^+ ions** to nitrate ions
- This is a two-step process:
  - $NH_4^+(aq) + 1½\ O_2(g) \rightarrow NO_2^-(aq) + 2H^+(aq) + H_2O(l)$
  - $NO_3^-(aq) + ½\ O_2(g) \rightarrow NO_3^-(aq)$

E6.2 – Tertiary, NO_3^- removal

- The nitrate ions originally present in waste water, along with those formed in the treatment of **NH_4^+**, are then **reduced** (by different strains of bacteria) **to nitrogen gas**, which is released into the atmosphere
- $2NO_3^-(aq) + 10e^- + 12H^+(aq) \rightarrow N_2(g) + 6H_2O(l)$

E6.2 – Tertiary, PO_4^{3-} removal

- Phosphates are removed by either **biological** or **chemical** processes.
- Water treated with biomass containing **specific bacteria which absorb the PO_4^{3-}** ions, and the product can later be used as fertilizer
- Alternatively, PO_4^{3-} ions can be removed by **chemical precipitation**
  - $Fe^{3+}(aq) + PO_4^{3-}(aq) \rightarrow FePO_4(s)$
  - $Al^{3+}(aq) + PO_4^{3-}(aq) \rightarrow AlPO_4(s)$

E6.2 – Tertiary, Heavy M removal

- Heavy metals can be removed by **chemical precipitation** or **ion exchange**.
- Most transition metal ions have **insoluble hydroxides**, so $Ca(OH)_2$ or Na_2CO_3 are added
  - **$Cr^{3+}(aq) + OH^-(aq) \rightarrow Cr(OH)_3(s)$**
  - A coagulant can then be added to clump and collect insoluble particles together
- Ion exchange resin is a material that binds reversibly to particular cations or anions as they are more **attracted to heavy metals** than original ions

$2Na^+(resin) + Cd^{2+}(aq) \rightleftharpoons 2Na^+(aq) + Cd^{2+}(resin)$

E6.3 – Fresh water from the Sea

- E.6.3 Evaluate the process to obtain fresh water from sea water using multistage distillation and reverse osmosis. (3)
- Osmosis is a natural process which serves to equalize the concentrations of solutions.
- If two solutions (one salt water, one water) are placed on two sides of a semi-permeable membrane, the water will tend to flow to the salt solution side until concentrations are in equilibrium
- If pure water is desired, we want the opposite and the solution **must flow against the osmotic flow**. This process is called **reverse osmosis.**

E6.3 – Reverse Osmosis

- Reverse osmosis requires that a **pressure be applied to the salt water**, greater than the osmotic pressure.
- This process takes energy because you must force the water through the membranes

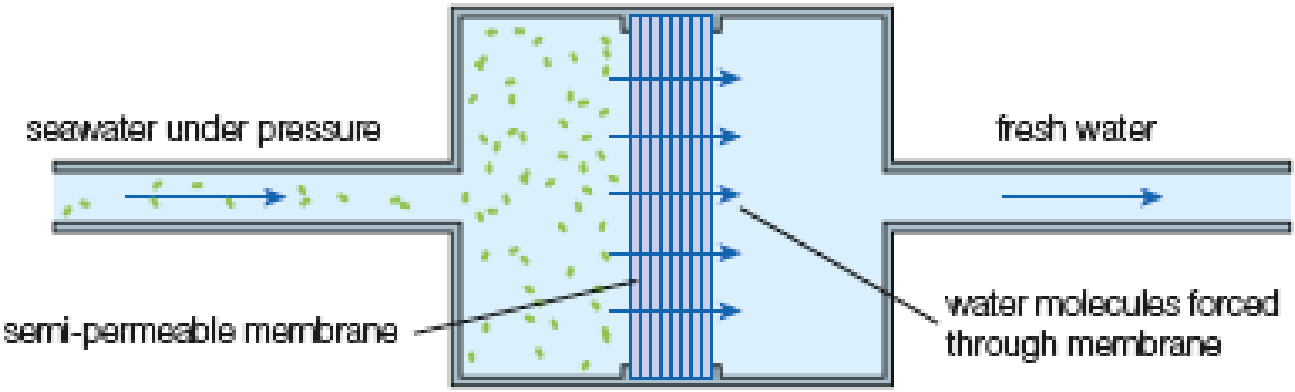


Figure 25.17 The principle of reverse osmosis

E6.3 – Thermal Desalination

- The most commonly used method to date is **multi-stage flash distillation** (MSF).
- Sea water is heated under high pressure and then passed into a chamber at lower pressure
  - Rapid decrease in pressure causes water to 'flash' evaporate
  - After each 'flash' the steam is cooled in another chamber
  - The cycle takes advantage of the steam to heat more water, keeping energy consumption minimized

E6.3 – Advantage of Different Methods of Attaining Fresh Water

Method	Advantages	Disadvantages
Reverse osmosis	Increasing energy efficiency as membrane and plant design improves. Lower carbon footprint as less fossil fuels are used.	Membranes can be a breeding ground for bacteria. Chemicals used for cleaning membranes can enter the environment.
Thermal desalination	Plants can utilize waste energy from thermal power plant (co-generation plant). Regions with water shortages (such as the Middle East) also have plentiful oil to provide energy for desalination.	Environmentalists are concerned about the 'carbon footprint' of desalination owing to its use of fossil fuels. Water is heated, so there is a possibility of thermal pollution as well as excess salt. Corrosion in the pipes can lead to copper entering the water outflow.

Table 25.5 Advantages and disadvantages of desalination methods